

most important among which is multiphoton ionization and cascade breakdown. According to [5,6], these effects do not arise if the following conditions are satisfied:

$$\theta_0 \leq \frac{10^2 |r_{21}| m \omega^2 I}{e^2 h \nu}, \quad \tau_p \geq 10^{15/\alpha} \left(\frac{e^2 \hbar \theta_0}{2 |r_{21}| m \omega^2 I} \right)^{\frac{\alpha+1}{\alpha}}, \quad (4)$$

where I is the ionization potential of the atoms of the medium, ν is the frequency of the elastic collisions of the electrons with the atoms, and α is the integer part of the ratio $I/h\nu$. The first condition of (4) limits the pulse energy as a result of the onset of cascade breakdown, while the second limits the pulse duration as a result of multiphoton ionization. At $\omega^2 \approx 2 \times 10^{30} \text{ sec}^{-1}$ (neodymium laser), $I = 6 \text{ eV}$, $|r_{21}| \sim 4 \times 10^{-24} \text{ cm}^3$, $\alpha = 6$, and $\nu = 10^9 \text{ sec}^{-1}$ ($N = 10^{16} \text{ cm}^{-3}$) (which is typical of alkali-metal vapors), the limiting value is $\theta_0 \leq 10^4$. If one applies at the entrance of a gas cell with the indicated characteristic a pulse with light-flux density $q \sim 10^9 \text{ W/cm}^2$ and duration $\tau_p \sim 10^{-9} \text{ sec}$ (with $\theta_0 \sim 10^2$ and $T_2 = 10^{-8} \text{ sec}$), then its components, in accord with the second condition of (4), can be narrowed down to $\sim 10^{-13} - 10^{-14} \text{ sec}^{-1}$ before multiphoton ionization sets in. The corresponding cell length should be $\sim 10^2 \text{ cm}$.

The described nonlinear coherent effect can thus be used to shape high-power ultrashort light pulses with durations $\tau_p \leq 10^{-14} \text{ sec}^{-1}$.

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ANISOTROPY OF THE HYPERFINE INTERACTION IN SINGLE-CRYSTAL $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}:\text{Fe}^{3+}$

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We report the results of an investigation of the Mossbauer effect on Fe^{57} impurity nuclei in single-crystal $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$. A sharp orientational dependence of the hfs splitting is observed, for the first time, in a weak external magnetic field $H = 300 \text{ Oe}$.

The hyperfine structure (hfs) of the Mossbauer line in a paramagnet, having in general a more complicated form than in magnetically-ordered substances, is extremely sensitive to weak external magnetic fields [1 - 4]. This sensitivity is due to the fact that in weak fields the states of the nucleus of the paramagnetic ion are mixed electron-nuclear states, so that the nuclear transitions alter the state of the electron shell of the ion. If the interaction of the electron spin \vec{S} with the magnetic field \vec{H} is comparable with the hyperfine interaction, it can become directly manifest in the hfs spectrum.

The effect of the field \vec{H} is known primarily as the "stabilization effect" [1], which consists in restoring the distinct hfs structure of the Mossbauer spectrum that had been smeared out by the random fields of the magnetic ions in the crystal and by external stray fields. In investigations of Fe^{57} impurity nuclei in polycrystalline samples, the stabilization effect was observed experimentally [2, 3], and these studies have demonstrated the possibility of obtaining information concerning the crystal field at the location of the Mossbauer ion.

So far, however, not a single experiment of this kind has been performed with paramagnetic single crystals, in which the hfs should depend not only on the magnitude but also on the direction of H relative to the crystallographic axes of the sample. The study of this dependence, with an aim at obtaining detailed information on the structure of the crystal field, and also at a more complete study of the relaxation phenomena in paramagnets, is in our opinion of considerable interest.

We report here the results of an investigation of the hfs of the Mossbauer line of impurity Fe^{57} nuclei in single-crystal $Al(NO_3)_3 \cdot 9H_2O$ with a monoclinic lattice having the parameters $a = 10.86 \text{ \AA}$, $b = 9.59 \text{ \AA}$, $c = 13.83 \text{ \AA}$, $\alpha = \gamma = 90^\circ$, and $\beta = 96^\circ 10'$ (space group $P_2 1/a$ [5]). The absorbing samples were prepared by slow evaporation of an aqueous solution of $Al(NO_3)_3$ containing 0.5 mol.% of $Fe^{57}(NO_3)_3$. Typical single-crystals grown by this method measured $\sim 15 \times 15 \times 5 \text{ mm}$.

In the investigation of the temperature dependence of the Mossbauer spectra it was established that the spin-lattice relaxation time of the Fe^{3+} ions at $T \leq 77^\circ K$ is long enough (see also [6]), and the line widths of the individual components remain practically unchanged in the temperature interval $4.2 - 77^\circ K$. This circumstance makes the compound $Al(NO_3)_3 \cdot 9H_2O$ quite convenient for the investigation of the Mossbauer effect on Fe^{57} impurity nuclei.

Figure 1 shows the Mossbauer absorption spectra obtained in the absence of a magnetic field and in a field $H = 300 \text{ Oe}$ perpendicular to the direction of the registered γ quanta ($H \perp k_\gamma$). We see that when the field is turned on the spectrum becomes symmetrical and new components appear in its central parts. A computer reduction of the spectra has shown that the new components correspond to one of three hfs components, of equal area, from individual Kramers doublets $D^{(i)}$ ($i = 1, 2, 3$; $v = 1, 2$) of the principal term ${}^6S_{5/2}$ of the Fe^{3+} ion, split by the crystal field. The fact that only one hfs spectrum is subject to the influence of H , and the other two "stable" spectra coincide, makes it possible, in accord with the results of [7], to reconstruct the spin Hamiltonian $\mathcal{H}^{(i)}$ for each isolated Kramers doublet $D^{(i)}$:

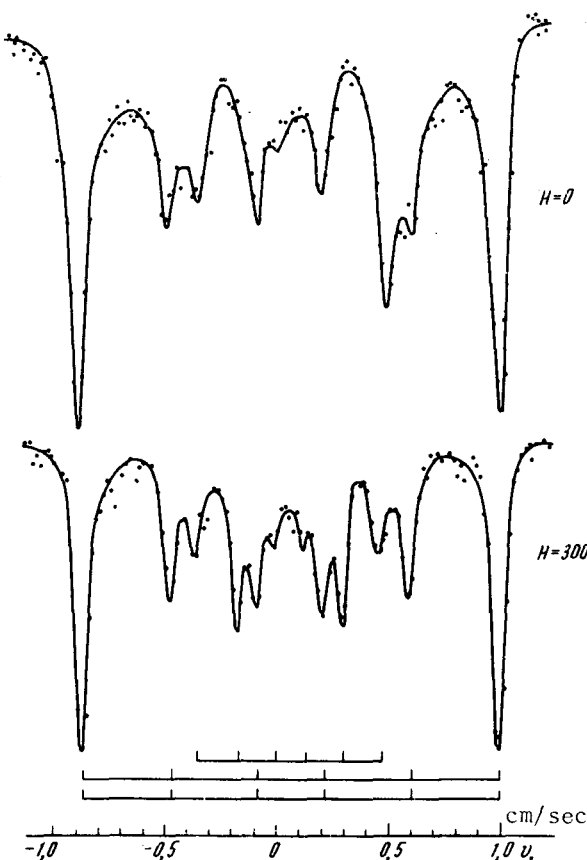


Fig. 1. Mossbauer absorption spectra of Fe^{57} nuclei in single-crystal $Al(NO_3)_3 \cdot 9H_2O:Fe^{3+}$ in a zero magnetic field and in a stabilizing field $H = 300 \text{ Oe}$ ($H \perp K_\gamma$) at $77^\circ K$. The source is Co^{57} in Cr .

$$\mathcal{H}^{(i)} = A_{xx}^{(i)} I_x S_x + A_{yy}^{(i)} I_y S_y + A_{zz}^{(i)} I_z S_z + \mu_B (g_{xx}^{(i)} H_x S_x + g_{yy}^{(i)} H_y S_y + g_{zz}^{(i)} H_z S_z),$$

where S is the electron spin, I is the spin of the nucleus, H is the magnetic field, μ_B is the Bohr magneton, $A_{jk}^{(i)}$ is the hyperfine-interaction tensor,

$g_{jk}^{(i)} = 2A_{jk}^{(i)}/A$ is the Lande factor, and A is the hyperfine interaction constant of the isolated ion. The parameters of the tensor $A_{jk}^{(i)}$ for the three doublets of this Hamiltonian are given in this case by

$$\begin{aligned} A_{xx}^{(1)} &= 4,8392 \text{ A}; & A_{yy}^{(1)} &= 0,3036 \text{ A}; & A_{zz}^{(1)} &= 0,4286 \text{ A}; \\ A_{xx}^{(2)} &= A_{yy}^{(1)}; & A_{yy}^{(2)} &= A_{xx}^{(1)}; & A_{zz}^{(2)} &= A_{zz}^{(1)}; \\ A_{xx}^{(3)} &= A_{yy}^{(3)} = A_{zz}^{(3)} & &= 2,1492 \text{ A}. \end{aligned}$$

The hyperfine interaction for the doublet $D^{(3)}$ is completely isotropic, and the corresponding hfs becomes smeared out by the weak random magnetic fields $H \sim 1 \text{ Oe}$ [$H \ll A/g\mu_B$ [1]]. The two other doublets, $D^{(1)}$ and $D^{(2)}$, as seen from the structure of the tensor $A_{jk}^{(1,2)}$, are sensitive to H only if the latter has a definite orientation relative to the sample. If the field H applied to the sample produces a Kramers-doublet splitting much larger than the hyperfine splitting, then we can use the following expression for the effective field H_n acting on the nucleus (see, e.g., [4]):

$$H_n = H_0 \left[\frac{(A_{xx}^4 \cos^2 \phi + A_{yy}^4 \sin^2 \phi) \sin^2 \theta + A_{zz}^4 \cos^2 \theta}{(A_{xx}^2 \cos^2 \phi + A_{yy}^2 \sin^2 \phi) \sin^2 \theta + A_{zz}^2 \cos^2 \theta} \right]^{1/2},$$

where the angles θ and ϕ determine the direction of the stabilizing field \vec{H} relative to the coordinate system fixed in the sample, in which the tensors $A_{jk}^{(i)}$ and $g_{jk}^{(j)}$ are diagonal.

It is easy to see that if the tensor $A_{jk}^{(1, 2)}$ is anisotropic ($A_{xx}^{(1)} \gg A_{yy}^{(1)} \approx A_{zz}^{(1)}$; $A_{yy}^{(2)} \gg A_{xx}^{(2)} \approx A_{zz}^{(2)}$), a sharp increase in the value of H_n must occur near the angle values $\phi = 0$ (XZ plane), $\phi = \pi/2$ (YZ plane), and $\theta = 0^\circ$ (OZ plane). Since the positions of these planes, and all the more the position of the OZ axis, are not known beforehand, their determination is a laborious experimental task.

The results of the orientation dependence of the hfs spectra are shown in Fig. 2. The angle $\alpha = 84^\circ$ corresponds to a direction of \vec{H} (relative to the crystallographic axes of the sample) near which a noticeable change in the hfs of one of the doublet sets in. When the angle α is varied, the components of one of the coinciding hfs spectra shift towards the center of gravity of the resultant Mossbauer spectrum. We see that at $\alpha = 96^\circ$ a change of only one degree in the direction of \vec{H} leads to a very strong change in the splitting of the hfs spectrum. This agrees with the condition that the field \vec{H} be near the planes XZ and YZ. As already noted above, a similar situation should occur also for the second hfs spectrum if the direction of \vec{H} is suitably chosen. If \vec{H} approaches the OZ axis, the splitting of both hfs spectra should decrease simultaneously.

We are presently carrying out detailed investigations of the anisotropy of the hyperfine interaction in $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}:\text{Fe}^{3+}$ for the purpose of determining the limit of the sensitivity of the hfs to the direction of the field \vec{H} .

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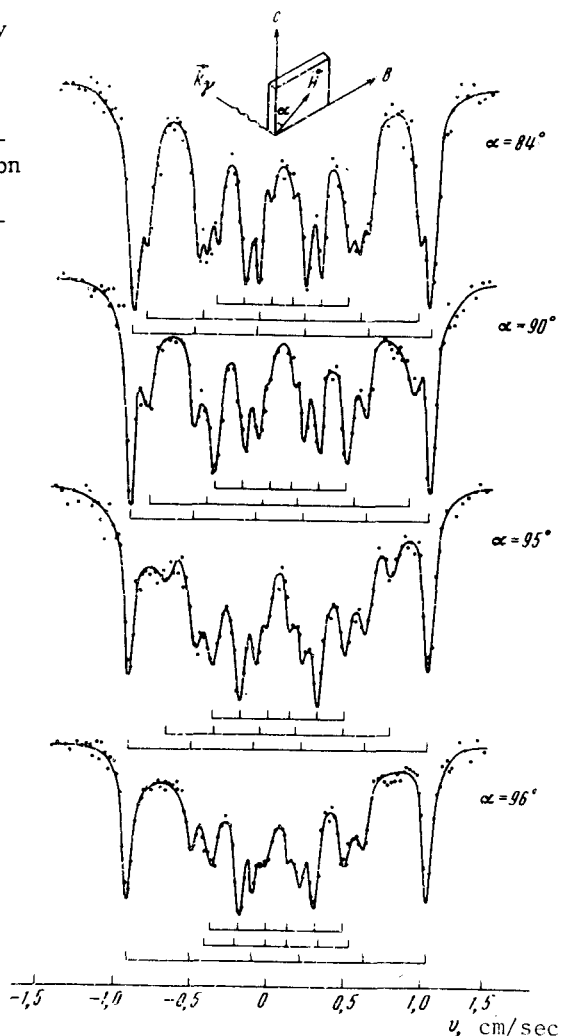


Fig. 2. Absorption spectra of $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}:\text{Fe}^{3+}$ at different orientations of the sample in a magnetic field $H = 300.0\text{e}$ ($\vec{H} \parallel \vec{k}_y$) at 77°K . The geometry of the experiment is illustrated schematically at the top.